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HIGH-VOLTAGE, HIGH-POWER TRANSISTORS. CHARACTERISTICS OF DEVELO--ETC(U)
AUG 60 D A KRUEGER, W M LAWSON
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HIGH-VOLTAGE, HIGH-POWER TRANSISTOR

Characteristics of Developmental Units

Interim Report No. 5

Donald A. Krueger
and
Wilmer M. Lawson, Jr.

SOUND DIVISION

17 August 1960

U. S. NAVAL RESEARCH LABORATORY
Washington, D.C.

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NRL Memorandum Report 1098

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HIGH-VOLTAGE, HIGH-POWER TRANSISTORS

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By

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Electrical Applications Branch
Sound Division
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ABSTRACT

Lot number 4 of 27 units, designated TA1801 developmental samples, have been received by NRL on ONR contract No. NOnr-2478(00). These units have been tested for breakdown and output characteristics, and tabular and photographic data are presented.

A curve-tracing circuit which will give common-base and common-emitter (with base open or shorted) characteristics is described. Also described are the modifications to a curve tracer for output characteristics and a test power-amplifier circuit.

The results of the tests in general were that the transistors do not yet meet the desired 300V breakdown and that the breakdown levels are less than those determined by RCA, 230-V average instead of 260-V average as given in RCA data. Operation in the test-amplifier circuit was tried but was unsuccessful.

PROBLEM AUTHORIZATION

NRL Problem No. 55S05-15
BUSHIPS Project NE 050 962, AS 02101, S-1834
ONR RF 001-03-43-4062

PROBLEM STATUS

This is an interim report on one phase of the project; work is continuing.

INTRODUCTION

A contract, NOnr-2478(00) has been negotiated for the Naval Research Laboratory by the Office of Naval Research with the Semiconductor Products Division of the Radio Corporation of America. This contract calls for the development of a 300-volt, 10-ampere, germanium power-transistor, capable of dissipating 150 watts at a 25°C mounting-base temperature. Twenty-seven samples designated "developmental units" and numbered TA-1801 have been received. All of the units are encased in the final "pipe-plug" design.

The results of the breakdown-voltage tests and the output characteristics of these units are presented.

BACKGROUND AND TEST PROCEDURE

In view of the relatively large number of samples involved in the latter phases of this contract, a permanent test circuit has been constructed which will present the three important voltage-breakdowns, BV_{ceo}, BV_{cbo}, BV_{ces}, on an oscilloscope. A schematic of this circuit is included as Figure 1. Basically, the curve tracer applies a half-wave, 60-cycle, sine-wave voltage to two of the terminals of the transistor under test. The collector current is then displayed on the X-axis of the oscilloscope through the current shunt, R_1, while the applied voltage is fed simultaneously to the Y-axis through the potential-divider circuit, R_2 and R_3. A current-limiting resistor, varying from 3KΩ to 151KΩ, is placed in series with the collector terminal to prevent excessive dissipation after breakdown. The Tektronix 515 oscilloscope is calibrated with a battery and a Weston Secondary-Standard voltmeter.

The collector-output characteristics (I_c vs V_{ce} with I_B held constant) are taken with the aid of the Dual Transistor Characteristic Curve Tracer, described in N.R.L. Memorandum Report No. 834, modified as shown in Figure 2. This modification is necessary to limit the internal power dissipation of the units to a figure compatible with their leakage and thermal-resistance parameters. From these output-characteristic curves, the saturation voltage, output impedance, and forward-current gain of the units may be computed. The accuracy of these measurements is limited by the accuracy with which the data can be read from the photographs, and therefore may contain errors as large as ±20%. As a result the quoted values of saturation voltage and current gain in this report cannot be compared rigorously to the data given by R.C.A., since their measurements of these parameters are direct measurements and are inherently more accurate. Even through the accuracy of the N.R.L. measurements is such that the two sets of data cannot be compared rigorously, the method was chosen because of its ability to present a better overall description of the performance of the transistor in a circuit.

TEST RESULTS AND DISCUSSION

The results of the voltage-breakdown tests on the individual units are presented in Figures 3 through 28 and in numerical form in Table I. The manufacturer's data on these units is included as Table II. It will be noted when comparing these two tables, that the N.R.L. data for the BV_{ceo} and BV_{ces} tests consistantly show a much lower breakdown voltage. To illustrate the margin of discrepancy, histograms have been prepared for the BV_{ceo} and BV_{ces} tests which show the number of samples which have a particular voltage span. Figure 29 compares the N.R.L. and R.C.A. BV_{ceo} tests; Figure 30 compares the BV_{ces} tests. Similar discrepancies have been found in the previous lots, (NRL Memo Reports 937, 1004 and 1042). Therefore, particular care was exercised in calibrating the test equipment. Other characteristics of the units as given by RCA are presented in a similar fashion in Figure 31.

It should be noted that a few of the samples initially exhibited breakdowns 30 to 50 volts in excess of the figures quoted in Table I. Under the normal test procedure, the circuit, Figure 1, is energized, and the voltage gradually increased until breakdown occurs. The circuit is then de-energized. When the circuit is re-energized, the full breakdown voltage is applied, and photographs of the characteristics are taken. However, on several of the samples, when the circuit was re-energized the breakdown voltage was as much as 50 volts lower than it had been previously. These units, when re-cycled many times, evidenced no further deterioration in their characteristics, but they never returned to their original state.

In this lot, as in a previous lot (N.R.L. Memo Report No. 1004) two of the units, see Figure 14 and 27, displayed a very peculiar breakdown in their collector-output curves. From the figures, it can be seen that the units function properly for the 25% and 50% base bias over most of the voltage range; however, near the peak-power-dissipation region, the units effectively short-circuit, collector-to emitter, but recover themselves and function properly on the 75 and 100% bias ranges. This phenomena was generally accompanied by a negative resistance characteristic, as well.

All of the previous tests performed on the units are static tests. In an attempt to collect data on the dynamic characteristics, the transistors were inserted in a class-B circuit operating in the common-collector mode, with transformer coupled input and output circuits. The common-collector mode was selected because of its ability to produce maximum output power, (i.e., the output current is the sum of the base and collector current). It has the further advantage that the two transistors can be mounted on the same heat sink and need not be electrically insulated from one another, thereby allowing more efficient cooling. A schematic of the test circuit is included as Figure 32.

The initial tests were performed with the transistors mounted on a water-cooled heat sink and operating at a collector voltage of 60

volts. Both units failed (collector-to-emitter shorts) at a total d.c. input current of 0.25 amperes. A second pair was inserted in the same circuit and also failed at approximately the same current. The collector voltage was reduced to 50, 40, and finally 30 volts. Although slightly higher currents and output powers were obtainable at these lower voltages (a maximum of 76 watts at a d.c. input of 3.25 amperes and 40 volts) all of the units tested, failed.

As a consequence of these results, Delco 2N174's were inserted in the same circuit, with the only change made to the circuit being the reversal of the polarity of the power supply to make the circuit compatible with the PNP transistors. The use of these transistors resulted in a maximum power output of 250 watts. This data was sufficient to indicate that the sample units themselves were malfunctioning and the tests were discontinued.

The remaining units, along with the destroyed units and a schematic of the test circuit were returned to the manufacturer, who is now attempting to determine the cause of the malfunction. To date, no word has been received from RCA as to possible causes of these phenomena.

SUMMARY AND CONCLUSIONS

1. The breakdown-voltage and output characteristics of the units are given in Figures 3 through 28 and in Table I.

2. The breakdown voltages are generally considerably less than quoted in the manufacturer's data.

3. Successful operation of the transistors in a common-collector mode was not achieved. Since 2N174 units operated quite satisfactorily in the same circuit, it appears there is some defect in the RCA transistors.

4. Test circuits and several destroyed and good transistors have been forwarded to RCA for analysis and comment.

TABLE I

N.R.L. [illegible]imental Data

TA-1801 [illegible]r Transistors

Unit No.	BV_{CBO} 1 ma	BV_{CES} 50 ma	BV_{CEO} 150 ma	h_{FE} $I_B \cong 100$ ma
10-1				
10-2	400+	230	120	28
10-5	400+	170	115	20
10-7	400+	240	130	18
10-9	400+	235	55	18
10-11	400+	210	60	14.5
10-18	400+	235	150	15
10-22	400+	240	150	13
10-24	400+	245	140	16
10-25	400+	150	70	13
10-26	400+	180	45	18
10-27	400+	235	40	
10-29	400+	180	65	
10-30	400+	235	135	18
10-31	400	210	70	19
10-32	400+	225	120	13
11-1	400+	225	45	23
11-3	350	230	50	24
11-7	400+	250	80	40
11-12	400	220	125	26
13-1	400+	215	5	
13-2	400+	270	135	12
13-6	400+	255	180	13
13-8	400+	245	200	13
13-11	400+	255	170	
13-12				14.5
13-13	400+	265	210	17

TABLE II
Manufacturer's Data - Developmental Samples
TA 1801 NPN Power Transistors

	BV_{CBO}	BV_{CES}	BV_{CEO}	BV_{EBO}	I_{CO}	h_{fE}	h_{fE}	$V_{ce}(sat)$	$F_{\alpha E}$	T.R.
Unit No.	1 ma	50 ma	150 ma	1 ma	5V(μa)	100 ma-I_c	10 A-I_c	10A-I_c 1A-I_b	MC	°C/W
10-1	400+	245	120	40	150	500	25.0	0.45	0.76	0.68
10-2	400+	245	200	120	60	250	16.0	0.40	0.68	0.36
10-5	400+	180	160	160	150	143	17.0	0.60	0.58	0.44
10-7	400+	270	170	5	110	250	25.0	0.35	0.55	0.66
10-9	400+	270	140	140	250		20.0	0.60	0.68	0.82
10-11	400+	230	100	150	300	170	17.0	0.35	0.72	0.59
10-18	400+	270	210	100	100	140	14.0	0.40	0.49	0.58
10-22	400+	270	210	130	140	125	12.5	0.40	0.48	0.45
10-24	400+	270	210	140	120	125	12.5	0.35	0.46	0.57
10-25	400+	200	170	140	120	250	12.5	0.50	0.47	0.86
10-26	400+	220	120	140	220	200	17.0	0.35	0.59	0.79
10-27	400+	260	120	120	150		14.0	0.40	0.46	0.67
10-29	400+	200	150	140	200	200	13.0	0.35	0.56	0.68
10-30	400+	265	210	100	80	170	17.0	0.35	0.44	0.71
10-31	400+	240	160	150	130	200	20.0	0.30	0.71	0.93
10-32	400+	240	180	150	200	143	12.5	0.35	0.49	0.38
11-1	400+	220	100	140	200	200	18.2	0.35	0.76	0.53
11-3	370	250	160	7	200	143	16.7	0.40	0.63	0.57
11-7	400+	270	130	80	150	170	25.0	0.30	0.62	0.59
11-12	400+	230	190	170	150	125	20.0	0.40	0.61	0.48
13-1	400+	260	120	150	220	170	12.5	0.50	0.53	0.71
13-2	400+	310	200	140	100	143	10.0	0.40	0.49	0.82
13-6	400+	290	220	160	140	111	8.3	0.40	0.44	0.62
13-8	400+	260	210	5	90	111	10.0	0.30	0.37	0.53
13-11	400+	270	200	130	80	286	10.0	0.35	0.54	0.28
13-12	400+	260	210	15	140	111	12.5	0.35	0.43	0.66
13-13	400+	290	240	160	70	143	14.3	0.80	0.42	0.74

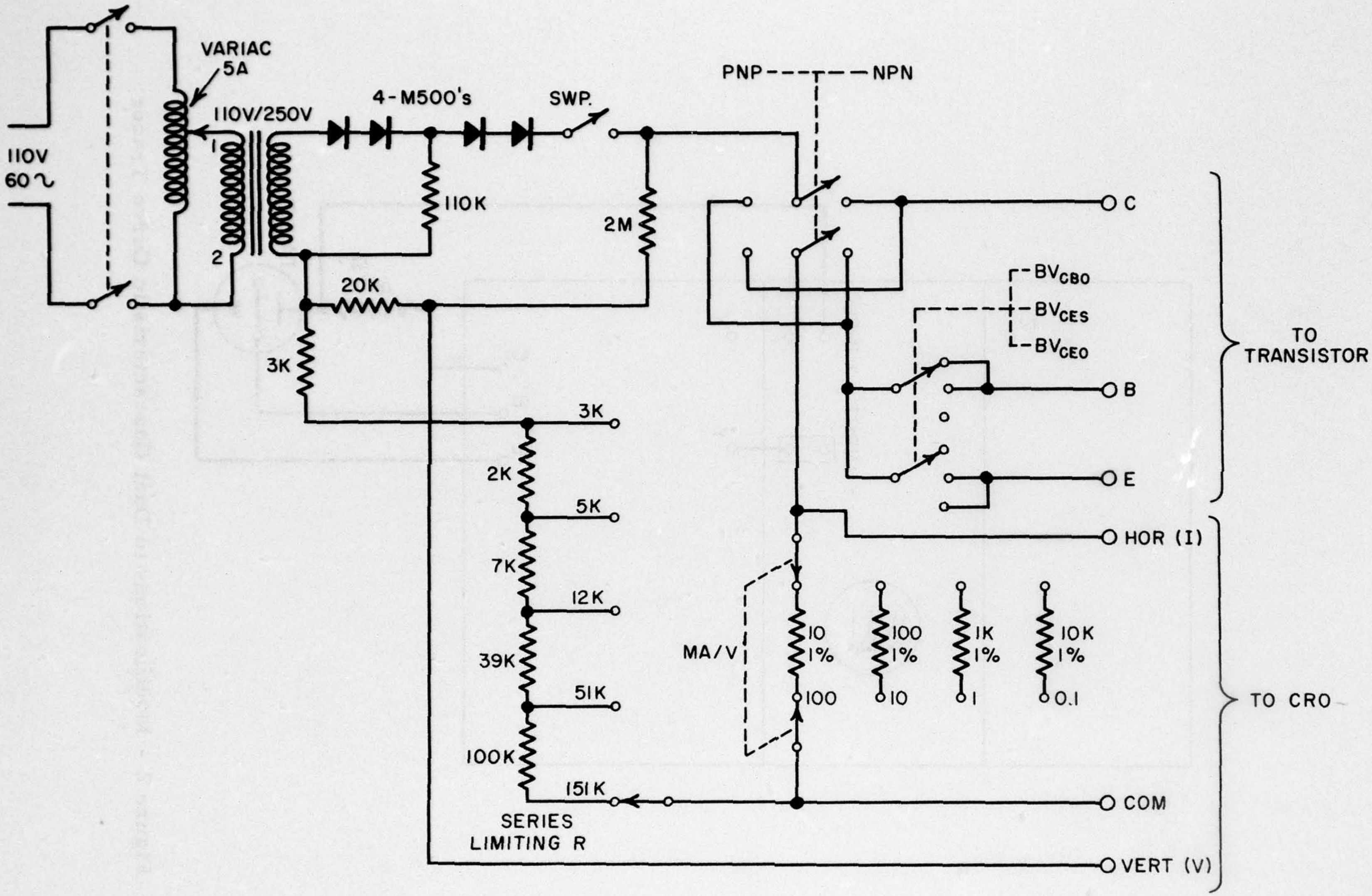


Figure 1 - Breakdown Characteristic Test Circuit

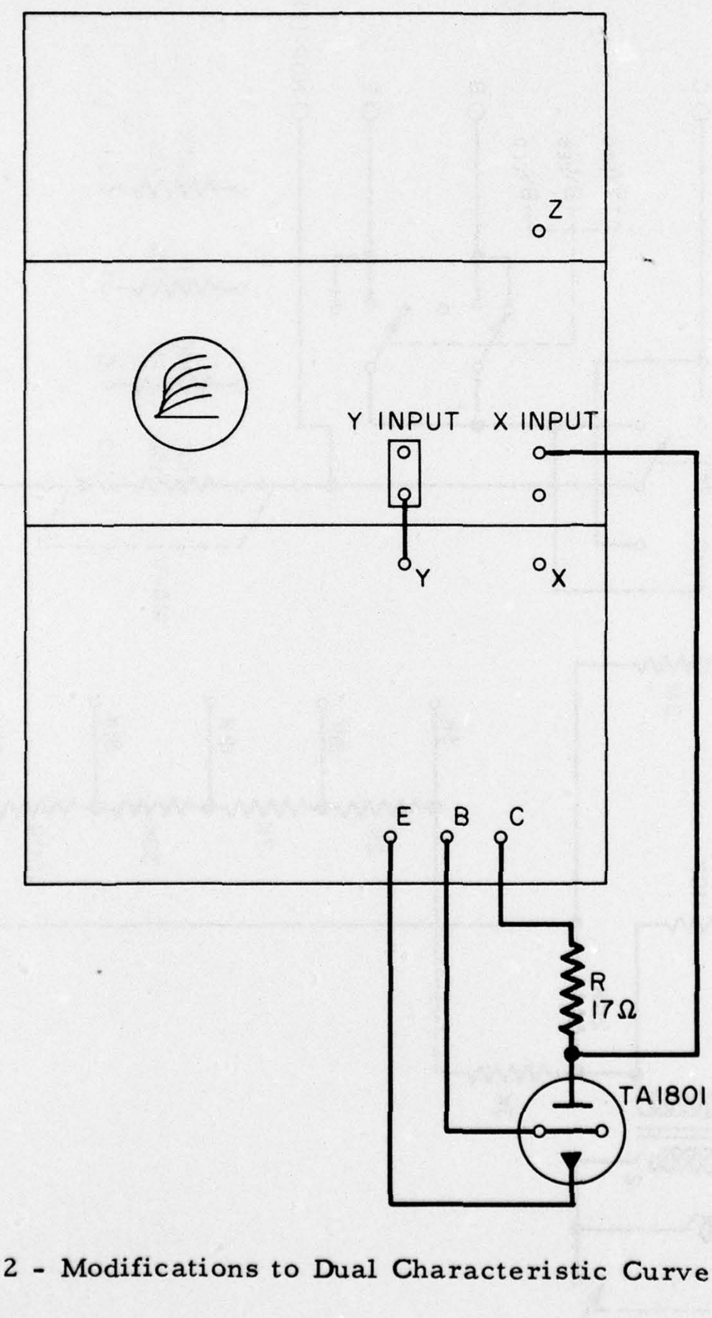
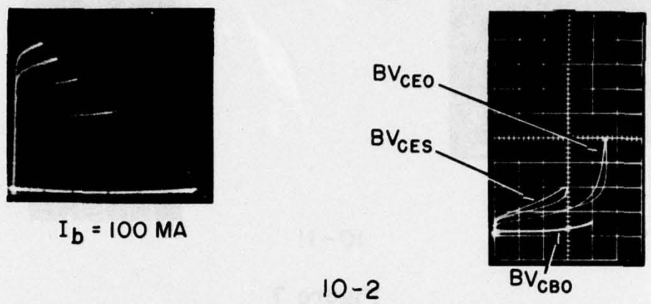


Figure 2 - Modifications to Dual Characteristic Curve Tracer

SCALES BELOW APPLY TO FIGS. 3 THROUGH 28:

HORIZ 3V/MINOR DIV.
VERT 200 MA/MINOR DIV.

BV_{CBO} 100V VS 1MA/MAJOR DIV.
BV_{CES} 50V VS 10 MA/MAJOR DIV.
BV_{CEO} 50V VS 10MA/MAJOR DIV.



I_b = 100 MA

10-2

Figure 3

I_b = 200 MA

10-5

Figure 4

I_b = 200 MA

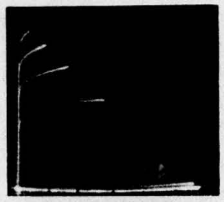
10-7

Figure 5

I_b = 200 MA

10-9

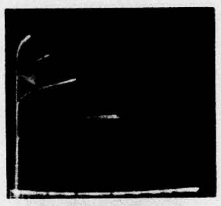
Figure 6



I_b = 300MA

10-11

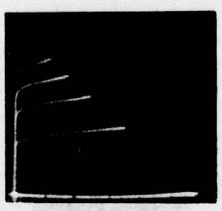
Figure 7



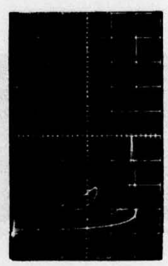
I_b = 300MA

10-18

Figure 8

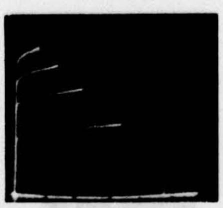


I_b = 300MA



10-22

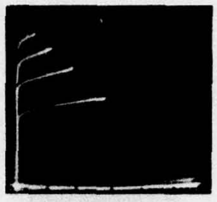
Figure 9



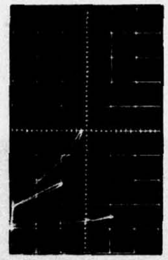
I_b = 300MA

10-24

Figure 10

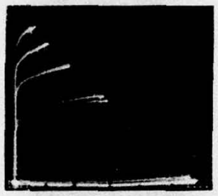


I_b = 300MA

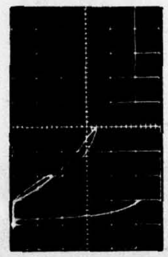


10-25

Figure 11



I_b = 200MA



10-26

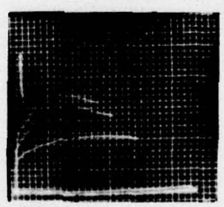
Figure 12

C TO E SHORT
DURING TEST

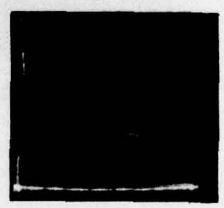
10-27

Figure 13

a



c



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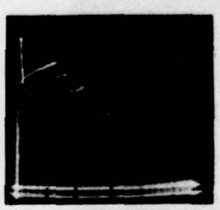
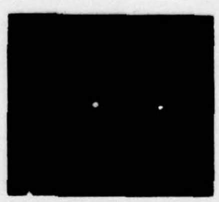


I_b = 100MA

b

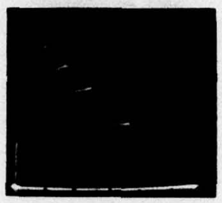


d

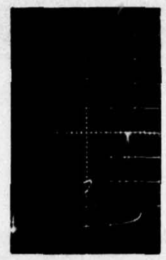
f

10-29

Figure 14



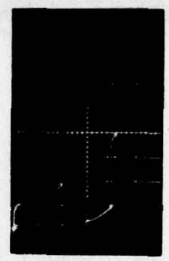
I_b = 200MA



10-30

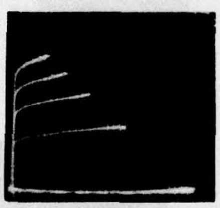
Figure 15

I_b = 200 MA

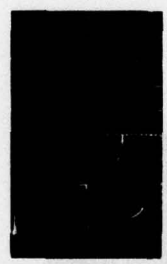


10-31

Figure 16



I_b = 300MA



10-32

Figure 17

I_b = 200MA

11-1

Figure 18

$I_b = 200MA$

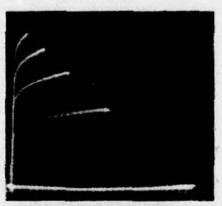
11-3

Figure 19

$I_b = 100MA$

11-7

Figure 20



$I_b = 200MA$

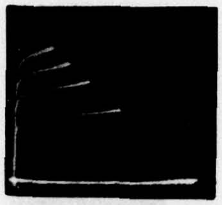
11-12

Figure 21

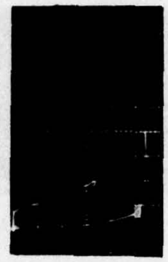
C TO E SHORT ON
25% BIAS RANGE

13-1

Figure 22

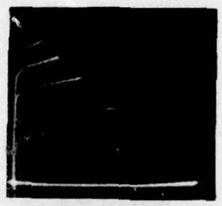


$I_b = 300MA$



13-2

Figure 23



$I_b = 300MA$

13-6

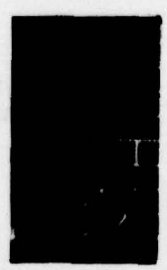
Figure 24

$I_b = 300MA$

13-8

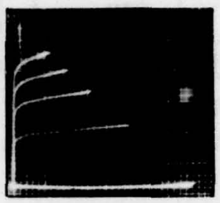
Figure 25

C TO E SHORT ON
25% BIAS RANGE

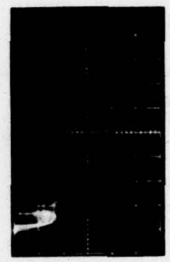


13-11

Figure 26

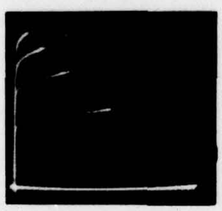


I_b = 300MA



13-12

Figure 27



I_b = 300MA

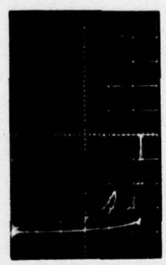


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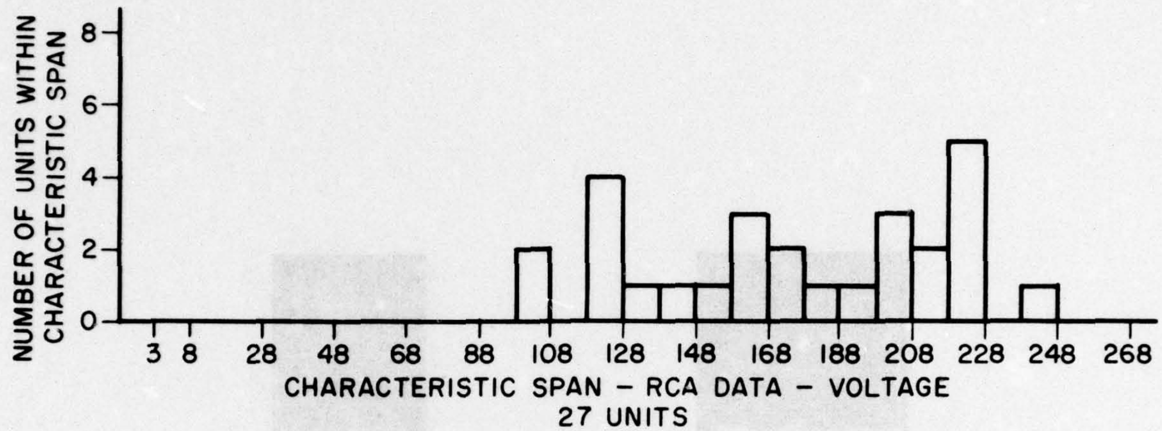
Figure 28



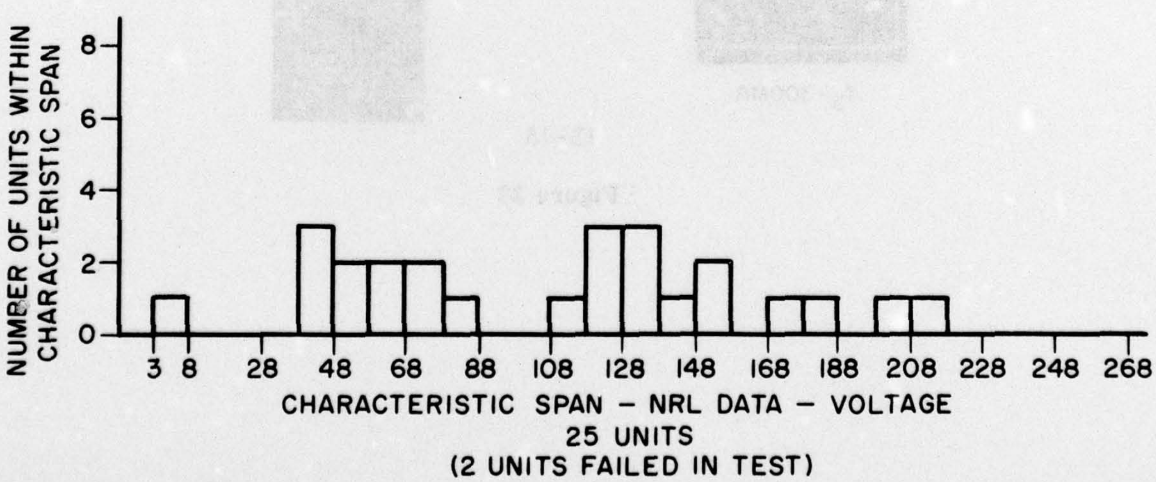
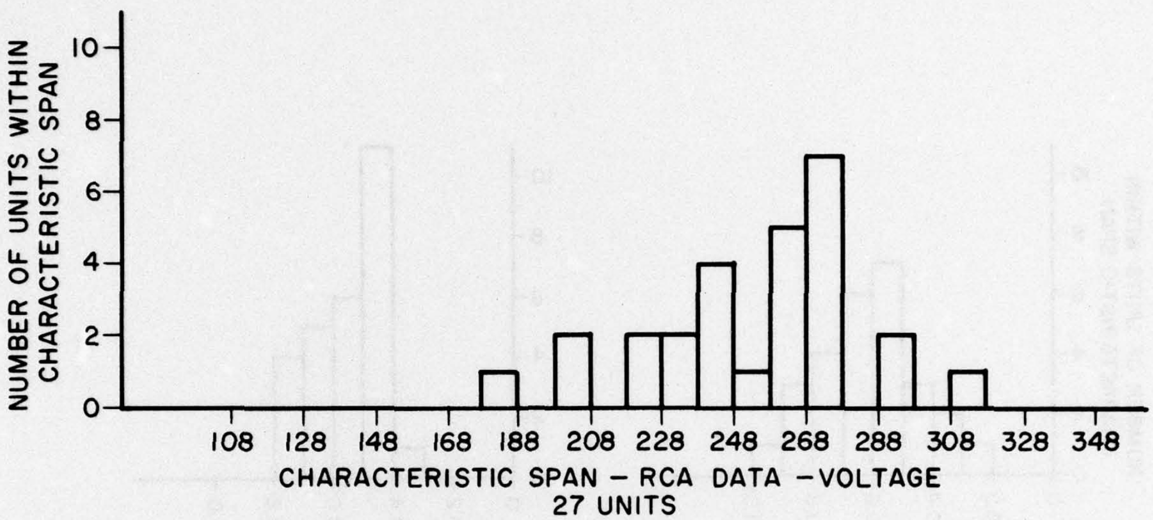


Figure 29 - Breakdown Voltage Characteristics RCA. TA-1801 N.P.N. Power Transistors BV_{ces}



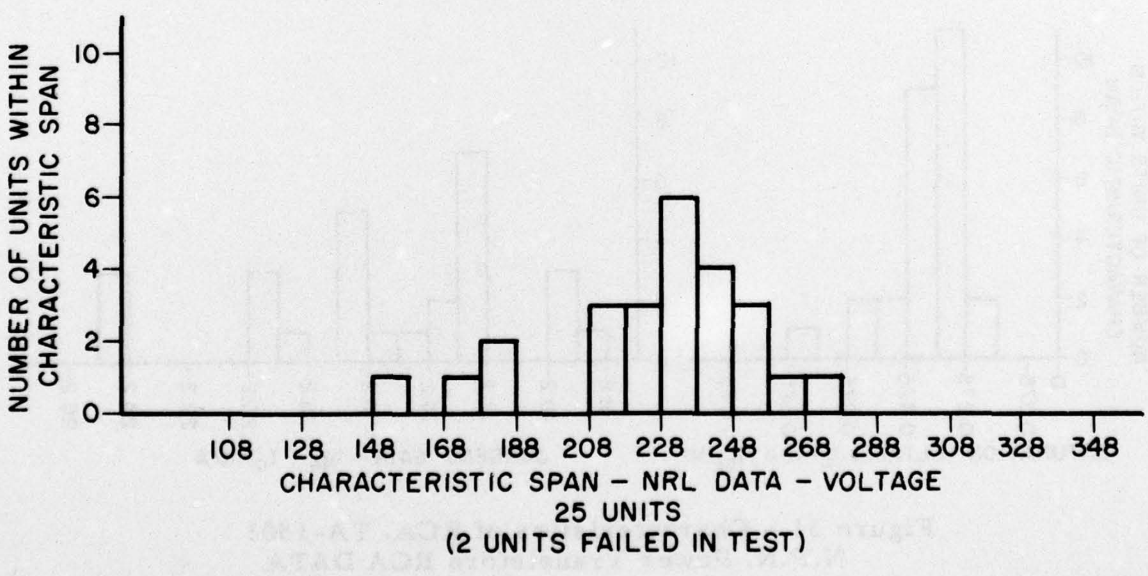


Figure 30 - Breakdown Voltage Characteristics RCA. TA-1801 N.P.N. Power Transistors BV_{ces}

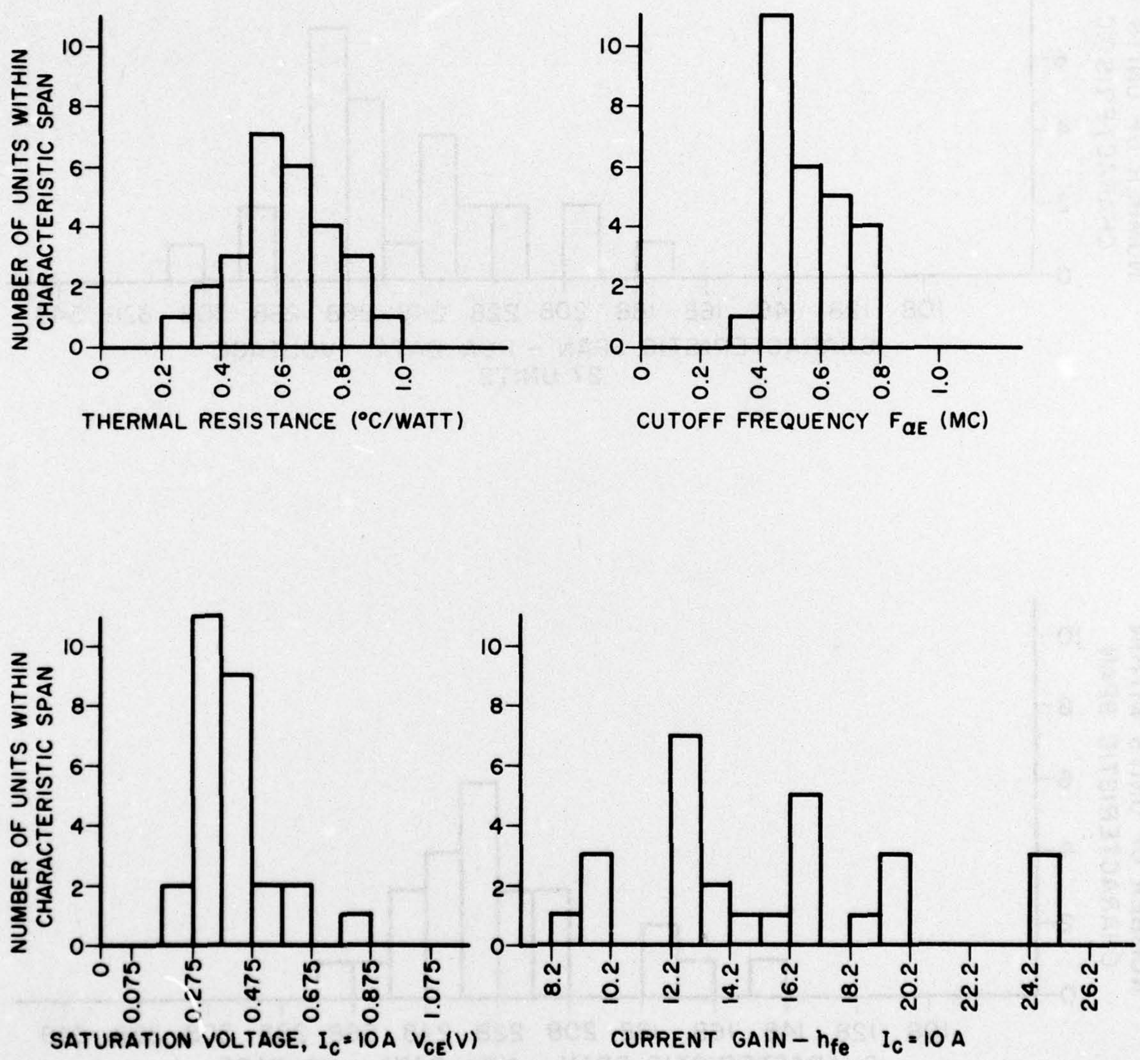


Figure 31 - Characteristics of RCA. TA-1801 N.P.N. Power Transistors RCA DATA

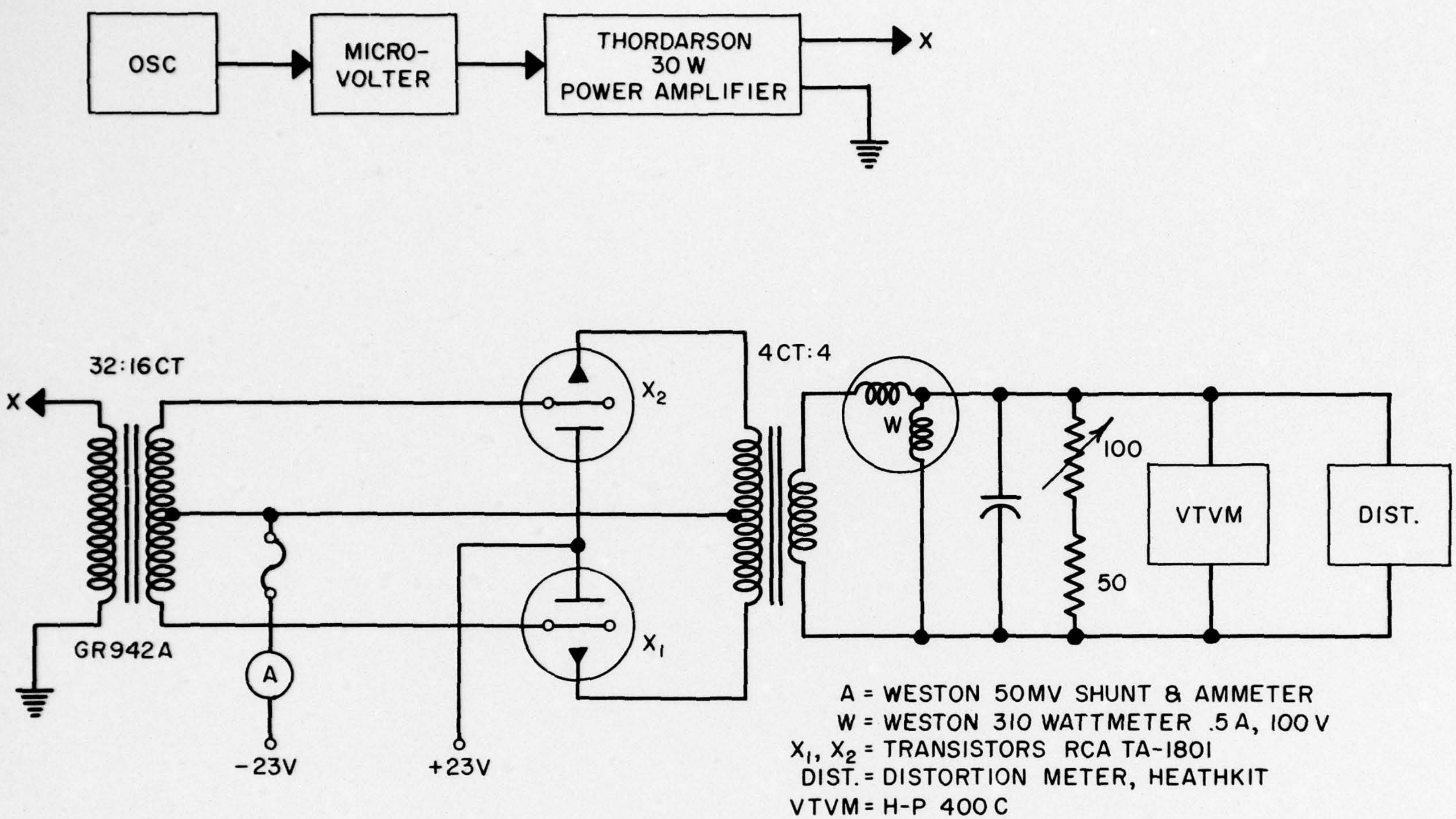


Figure 32 - Test Amplifier for TA-1801 Transistors